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An Intelligent Coaching System for Therapy Adherence

The eMate intelligent coaching system exploits the Computerized Behavior Intervention model to determine why a user acts in conflict with his or her health goals. Using a mobile phone app and an online lifestyle diary, eMate sends the user tailored information to motivate behavior change.

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A healthy lifestyle can help prevent the development of chronic diseases and the related complications. Yet despite knowing the benefits of a healthy lifestyle, people still find it difficult to maintain a good balance between work and their social lives, and eating a healthy diet or regularly taking medication. Consequently, the number of people with obesity or chronic disease—such as type-2 diabetes or cardiovascular disease—has increased considerably over the past few years, and the prevalence and costs of interventions to address the burdens of chronic disease are expected to rise.[1]

Computerized intelligent self-management or coaching solutions can help motivate people to maintain healthy behaviors without requiring expensive therapists or caregivers. Using computers to increase self-management has proven effective.[2] Coaching systems can constantly provide personalized interventions at low cost and at home.[3] Interventions that are closely tailored to the individual's convictions and motivations are more likely to be read and remembered.[4] Although intelligent coaching assistants are becoming increasingly popular in behavior interventions, such assistants are rarely based on computational models of behavior change.

Designing an effective support system requires formalizing the underlying mechanisms of behavior change. Here, we present the *Com*puterized *B*ehavior *I*ntervention (Combi) model, which we developed based on theoretical frameworks of behavior change.[5] The Combi model is the core of eMate, an intelligent support system that interacts with users via a mobile phone and website. The system uses the model to understand human behavior and detect the causes of unhealthy behavior, providing users with tailored information and motivational messages to help them improve their behavior. Here, we provide a general overview of eMate, focusing on user interaction and how the system applies reasoning methods in automated coaching.

Intelligent Coaching and Mobile Persuasion

Many contemporary approaches for coaching solutions use a mobile phone, which is easily available to the user and supports both user- and system-initiated interactions. Information provided by the mobile phone can be personalized and designed to persuade or manipulate the user, which makes the phone an ideal platform for inducing behavior change. The simplest approach to supporting behavior change is as

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a reminder system, which doesn't use complex persuasive techniques. Instead, such systems use simple messages to remind patients of the desired behavior.

More complex systems provide tailored feedback based on user data. Most of these systems use some kind of human coaching as a supplement—for example, a person who gives the user the feedback messages or tracks the user's progress.

Supportive systems that don't rely on human coaches are less common, but recently this area has received more attention. Such systems can use predefined algorithms to select feedback messages from a large pool of preformulated texts. Systems that use mobile phones to send tailored text messages might directly or indirectly influence user behavior determinants central to many behavioral theories. It's thus important to design the messages such that their tone is in line with persuasive theories, and they incorporate knowledge of behavioral theories.

Moreover, data suggests that intervention programs have a greater effect when the message content is theory based.[6] Android's Play Store and Apple's App Store are full of apps that promise to help users manage their health goals or provide reminder and coaching messages. However, few mobile health interventions targeting therapy adherence or disease management are based on validated psychological theories.[7]

Our approach differs from previous approaches in that it targets not only the user's behavior but also the underlying mechanisms causing that behavior. The mechanisms are described in the Combi model, which is based on multiple psychological theories related to determinants for behavior change. The eMate system then provides tailored feedback on the relevant individual determinants of nonadherence. Furthermore, it uses validated persuasion techniques without relying on a human coach. It's an integrated system that uses questionnaires, a telephone message service, an online diary, and an information portal to support three lifestyle domains: medication, diet, and exercise.

Modeling Behavior Change

The Combi model attempts to integrate several psychological theories on behavior change into a formal representation. The model draws inspiration from seven influential theories of behavior change: the transtheoretical model,[8] social cognitive theory,[9] self-regulation theories,[10] the theory of planned behavior,[11] attitude formation,[12] the health belief model,[13] and the relapse prevention model.[14] We selected these theories for three main reasons.

First, they're frequently and successfully used for behavior change intervention.[15,16]

Second, they cover different perspectives of human behavior determinants. Theories or models often have a limited perspective of behavior determinants so they can be more comprehensive and easy to use in follow-up research, yet human behavior involves complex interplay between multiple determinants. Moreover, while most theories are constructed either to explain behavior or to change it using interventions, we aim to do both.

Third, the most prevalent behavior change theories have common constructs with sometimes different names. Integrating these theories with their different scopes thus provides an opportunity for a broader and more complete picture of human behavior determinants at an individual level. The chosen theories will hopefully provide a unique insight that helps us better understand multiple facets of behavior so we can develop computerized interventions.

The transtheoretical model, which forms the core of the Combi model, has been successful in many programs aimed at eliminating addictive behavior, improving mental health, encouraging users to exercise, or supporting dietary changes.[16] It assumes that behavior change is a five-stage process involving *precontemplation*, *contemplation*, *preparation*, *action*, and *maintenance*. Furthermore, it implies that the kinds of interventions needed to move from one stage to another differ per stage, because each stage represents specific stages of readiness for change, depending on the individual's *awareness*, *motivation*, and *commitment*. Although people advance through the stages sequentially, they can also relapse to a previous stage.

In the Combi model, the determinants and their relation as identified by the literature are brought together, as Figure 1 shows. The transtheoretical model's stages of change are represented as five circles at the bottom of the figure. The main determinants that influence these stages are awareness, motivation, and commitment, which in turn are composites of determinants higher in the graph hierarchy (see Table 1). We give a more elaborate description of the model and the relation to psychological literature elsewhere.[5]

The model differentiates between internal and external determinants of behavior. External determinants are depicted beyond the dotted line, but note that some determinants are both internal and external. This represents the possible discrepancy between "objective" determinants that exist in the world and the interpretation or perceived applicability of these determinants as identified by a person.

The determinants in the model have a causal hierarchy between them. *Susceptibility* and *severity* represent how one perceives the severity of the consequences of the performed behavior and the likeliness of being affected by them. They are two of the six determinants of perceived behavior according to the health belief model.[13] Together, they influence the amount of *threat* a person feels with regard to the consequences of not changing his or her behavior. To give an example, although people might be aware of the serious consequences of an unhealthy diet over long time periods (such as higher risk of obesity, bone fractures, and chronic illness), they might not feel that they'll actually be affected by such consequences.

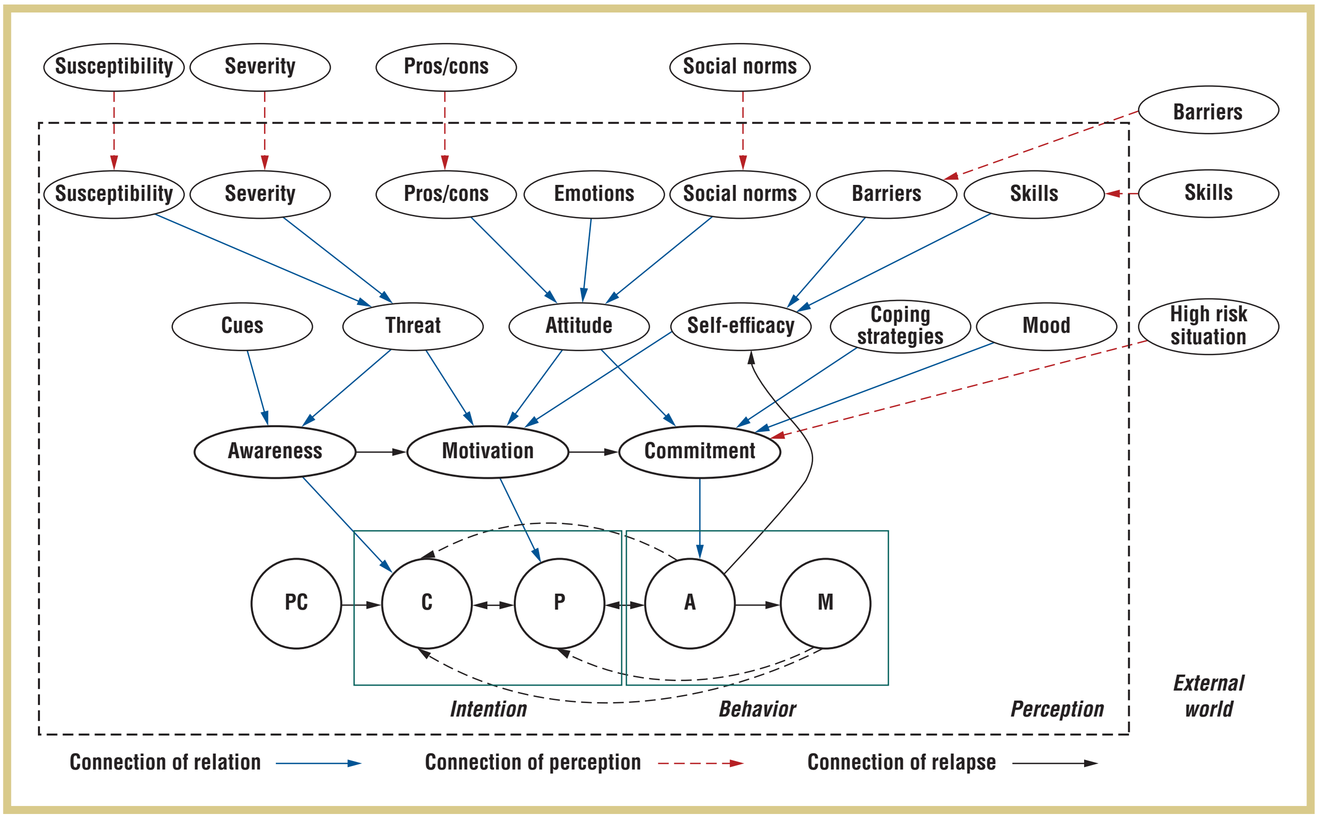

Figure 1. The Computerized Behavior Intervention (Combi) integrated model of behavior change. The transtheoretical model's five stages of change are represented as circles at the bottom: precontemplation (PC), contemplation (C), preparation (P), action (A), and maintenance (M). The main determinants that influence these stages are awareness, motivation, and commitment, which in turn are composites from determinants higher in the graph hierarchy.

The health belief model also explicitly incorporates motivation, which is influenced by several determinants in the model. The *pros and cons* correspond to the beliefs about the importance of the behavior change. Many theories endorse the importance of such beliefs in the process of behavior change—including the theory of planned behavior,[11] attitude formation,[12] and the health belief model.[13]

Emotions cover how a person feels in relation to changing a particular behavior and include cognitive appraisals related to this change. In the self-regulation theories, emotions and *mood* can greatly influence behavior.[10] (Mood is a temporary state of mind that's defined by feelings and dispositions.) *Social norms*, addressed in the planned behavior and reasoned action theories,[11] reflect the influence of a person's culture and environment. One of the main contributions of the attitude formation theory is the idea that pros and cons, emotions, and social norms affect a person's *attitude*, which encompasses a more general disposition toward adopting new behavior.

According to the health belief model, another prominent determinant of behavior is the *barriers*, which correspond to obstacles that prevent someone from adopting a new behavior. People can identify barriers, such as not having a gym in the neighborhood or having an irregular work schedule.

Skills determine a person's experiences and capabilities for overcoming these barriers. Skills play an important role in planned behavior and social cognitive theories.[9] Barriers and skills contribute to *self-efficacy*, which is defined by social cognitive theory as confidence in your ability to complete tasks and reach (behavior change) goals.

The relapse prevention model[14] focuses on *high-risk situations* and coping skills. Such situations are certain contexts with the ability to influence your behavior. Examples are negative emotions resulting from interactions with others, such as pressures or *cues* in the environment that lead to a particular behavior—for example, walking by a hotdog stand when your goal is to eat healthy foods. *Coping strategies* refer to the ability to deal with and overcome such high-risk situations. More specifically, coping consists of cognitive and behavioral strategies to deal with the demands or challenging or difficult situations.

The health belief model also identifies cues that are important to behavior change. These cues refer to the physical or mental cues individuals experience

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TABLE 1
The model's behavior determinants and the related theories.

Construct	Description	Related theory
Susceptibility	The likelihood of being affected by the behavior's consequences	Health belief model
Severity	The severity of the behavior's consequences	Health belief model
Pros/cons	Beliefs about the importance of behavior change	Theory of planned behavior Attitude formation Health belief model
Emotions	Feelings and cognitive appraisal related to the behavior change	Social cognitive theory Attitude formation
Social norms	The influence of a person's culture and environment	Theory of planned behavior Attitude formation
Barriers	Practical obstacles that prevent behavior change	Health belief model
Skills	Experiences and capabilities to overcome barriers	Theory of planned behavior Social cognitive theory
Cues	Environmental or physical stimuli	Health belief model
Threat	Perceived risk of continuing to perform the behavior	Health belief model
Attitude	A mental state involving beliefs, emotions, and dispositions	Theory of planned behavior Attitude formation
Self-efficacy	Perceived behavioral control	Relapse prevention model Social cognitive theory Theory of planned behavior
Coping strategies	The ability to deal with tempting situations and cues	Self-regulation theories Relapse prevention model
Mood	A temporary state of mind defined by feelings and dispositions	Theory of planned behavior
High-risk situations	Contexts and environments that influence a person's behavior	Relapse prevention model
Awareness	Conscious knowledge of your condition and the threat and influence of current behavior	Transtheoretical model
Motivation	Incentives to perform goal-directed actions	Health belief model Transtheoretical model
Commitment	An intellectual or emotional binding to a course of action	Transtheoretical model

as a consequence of their behavior—such as physical discomforts resulting from obesity or chronic illness. Such discomforts strongly affect the awareness that a change in behavior might be beneficial or necessary.

Finally, commitment is influenced by a multitude of determinants, including coping strategies and mood, which includes more general feelings and a state of mind (not related to the behavior).

The eMate System

Using the Combi model as the basis for the eMate coaching system, we aimed to support patients with diabetes mellitus type 2, HIV, or cardiovascular disease. The goal was to help such patients adhere to therapy plans, which comprised lifestyle advice and precise instructions for taking medication. We've developed a mobile phone app for the Android and iPhone platforms that can pose questions and send messages to the user. Through this mobile phone, the system can monitor the user continuously and adapt to changes in the factors that determine his or her behavior.

Identifying Patient Behavior

The system monitors user behavior in several ways. On the website, users can list their health-related activities (such as food intake and exercise schedule). Moreover, eMate regularly asks the user via the phone app whether he or she performed scheduled physical activities (see Figure 2a) and ate healthy foods (Figure 2c). The user's medication intake is measured directly with the help of an electronic pillbox that registers when it's opened and can send reminders www.evalan.com/projects/medication.

Finding Bottlenecks

The eMate system offers personalized support and advice to the patient. It gives the patient motivational and informative messages that focus on the psychological constructs that influence the undesired behavior for this specific patient—that is, specific bottlenecks to behavior change.

This bottleneck is determined using the Combi model and is defined as the construct in the graph that prevents a patient from progressing from

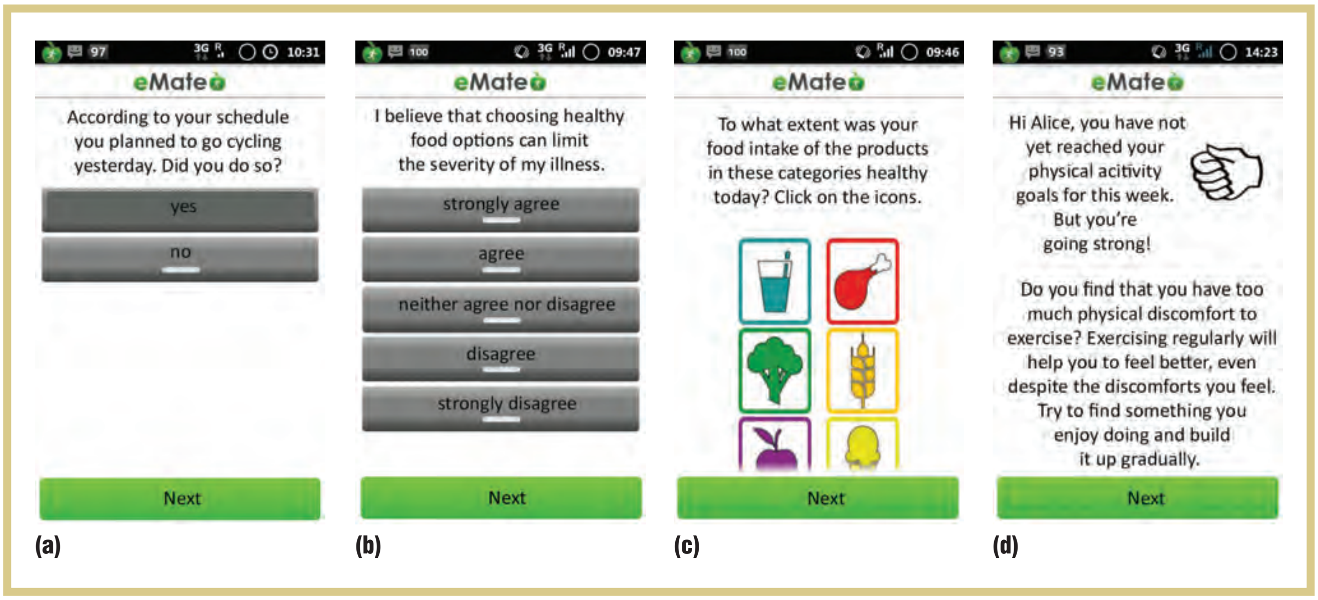

Figure 2. Screenshots of the eMate telephone app (the original text is in Dutch): (a) Diary update for exercise, (b) a question concerning severity, (c) a question on food intake, and (d) a status update and motivational message.

one stage of change to another. First, the stage of change of a patient is determined (see the circles in the lower part of the model in Figure 1) via an online questionnaire. The questionnaire is a combination of several validated questionnaires to determine the behavior in each of the three domains (food intake, medicine intake, and exercise behavior), and consists of around 90 questions. While the patient is using the system, these stages are compared with the reported and measured behavior, and, if necessary, updated.

Next, the system will investigate whether the constructs that influence the next stage of change—that is, the determinants that are related to that stage by an incoming arrow—might be a bottleneck for the change of the behavior. For example, if a patient is in the preparation phase, the system will investigate the constructs that are related to the action phase. More specifically, it will investigate the constructs that are in the paths connected to the action phase. A path consists of a sequence of edges that connect a sequence of constructs.

The reasoning mechanism evaluates possible bottlenecks in the paths by obtaining up-to-date values through posing one or two questions via the mobile phone that assess this specific construct for the patient. Figure 2b shows an example question for investigating the patient's perception of the severity of his or her disease. If the user's answer shows that this construct might indeed be problematic, the constructs that influence this construct are subsequently investigated.

A semiformal notation of this process is described by the algorithm in Figure 3. Once the bottlenecks are established, eMate prioritizes them according to their *urgency*—that is, how low the value of the construct is for the user—and their *changeability*, which is a parameter that represents to what extent the user can change this construct. For example, the perceived social norms are more difficult to change than his or her knowledge of the pros and cons of adopting a new behavior.

This mechanism exemplifies a model-based diagnosis.[17] By using the algorithm sketched on a causal model, the system prunes away constructs that aren't relevant for explaining the current behavior. Then the system asks only questions necessary to determine the bottleneck obstructing the healthy behavior.

Personalizing the Messages

By applying model-based reasoning, eMate can address the right problems at the right time. Each week, the user receives an intervention message for each of the three domains (see, for example, the message shown in Figure 2d). These messages adhere to the principles of motivational interviewing, which have proven effective for coaching and therapy.[18] The eMate system can, for example, express empathy, cheer on and compliment the user, and support the user's self-efficacy and positive emotions.

All messages are designed to minimize user boredom and annoyance (common reactions to tailored health messages in Web-based solutions[2]). Specifically, eMate sends messages that can be read in their entirety on the display of an average smartphone (3.3 inches), minimizing the user's need to scroll. Furthermore, eMate automatically composes the messages from three separate components: a status update for the user, a motivational message targeting the user's bottleneck, and a link to the relevant part of the website with more information. Because these three components have several instantiations and are dynamically composed (taking into account previously

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C ← the set of all constructs in the model graph
S ← the ordered set of all stages of change: {PC < C < P < A < M}
s_i ← the current stage of change s_i of the user, s_i ∈ S
s_j ← the stage that directly succeeds s_i, s_j ∈ S
τ_i ← the threshold for construct i
l_i ← the lifetime for a value of construct i
bottleneck ← list of bottlenecks, initially empty
for all c_k ∈ C do                                          ▷ cycle through all constructs linked to the stage
    if connected(c_k, s_j) AND age(c_k) < l_k then
        INVESTIGATE(c_k)
    end if
end for

function INVESTIGATE(construct c_i)
    update c_i                                              ▷ ask user questions about this construct
    if value(c_i) < τ_i then                                ▷ up-to-date value is indeed below threshold
        bottleneck ← bottleneck + c_i
        for all c_{j≠i} ∈ C do
            if connected(c_j, c_i) AND age(c_j) < l_j then  ▷ recursively investigate constructs on this path
                INVESTIGATE(c_j)
            end if
        end for
    end if
end function
```

Figure 3. The algorithm describing the semiformal notation of the eMate process of finding bottlenecks.

sent messages), the user rarely receives the same message twice. (Note that the system was designed for approximately three months of use.)

The related eMate website gives an overview of the extent to which the user has reached his or her goals in the past week, represented as a percentage and with an iconic thumb (see Figure 4a). The website also displays the user's progress on the three different domains. For example, users can see how well they're doing with the medication, as Figure 4b shows.

System Implementation

The system is implemented via a generic architecture (see Figure 5). Central to the architecture is a database containing the values of all concepts for the patients as well as all questions and messages. The reasoning server updates the information hourly in the database, according to the rule set that defines the model-based diagnostic process. If the outcome of the process is that a message should be sent or a question posed, the system registers this in the database, noting that a specific question or message should be communicated to the user.

The mobile phone app connects every 15 minutes via a Web service to the database. When connecting, the app fetches the open questions and messages and answers previous questions, which are subsequently processed by the reasoning engine. The website connects to the database as well and presents open questions to the user.

User Data Analysis

Currently, development and testing of eMate is a work in progress. We have, however, done some formative testing to validate the model and diagnose and fix any problems users have encountered while using eMate in daily settings. Additionally, we've analyzed the results of eMate's reasoning method based on user-provided data. Even though we can present only limited metrics and statistics, these results provide interesting insights, not only for the future development of eMate but also for other approaches that use interventions for behavior change.

Model Validation

We performed this study to gain insight into the validity of the Combi model and the quality of the data obtained from the questionnaire. Forty healthy subjects participated in the study (20 men and 20 women, ranging in age from 21 to 64, with a mean age of 33 years), filling out an anonymous online questionnaire with 42 questions targeting adherence to physical exercise.

The questionnaire included three externally validated questionnaires: the Utrecht Proactive Coping Competence survey (https://easy.dans.knaw.nl//ui/

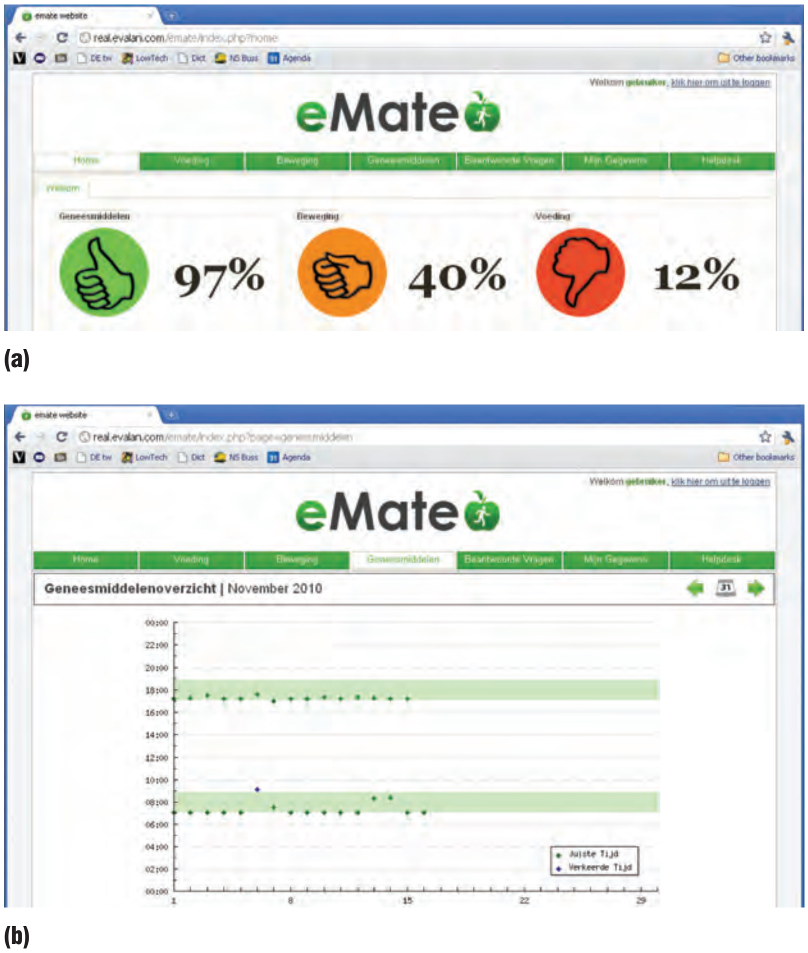

Figure 4. Screenshots of the eMate website: (a) an overview of goal achievement, and (b) the user's medicine intake.

datasets/id/easy-dataset:53011?dummytag=archivenie), the Positive and Negative Affect scale (to assess mood),[19] and the Short Questionnaire to Assess Health-Enhancing Physical Activity (Squash) questionnaire[20] (to assess physical activity). The physical activity variable considered in the analysis represents the self-reported number of days of physical activity per week, extracted from the respondents' answers in the Squash questionnaire. The remaining constructs were measured with one or two questions addressing the determinant of interest. The questions were either open or formulated with multiple-choice answers, recorded on 3-, 5-, or 6-point Likert-scale.

The results demonstrated significant correlations between susceptibility and threat and between the number of days of physical activity and threat, attitude, self-efficacy, mood, and cues. The early results were encouraging. We identified the following main patterns (Pearson correlations, $p < 0.05$):

- The constructs at the second level of the model—such as cues, threat, and attitude (see Figure 1)—could be good predictors for the state of behavior change. All constructs at this level had significant correlations with the measure of physical activity.
- Experiences of cues and threat might negatively influence physical activity: we found significant negative correlations between both threat and physical activity and between cues and physical activity.
- The relations between the first- and second-level constructs, and between the first-level constructs and psychical activity, are in line with expected trends. Although these results weren't significant, they showed intuitive relations, such as positive correlations between the constructs at the first and second level and negative correlations between barriers and self-efficacy.

The first finding shows us that interventions that address second-level constructs should be given priority, because they seem essential to the process of behavior change. For example, if the value of attitude is low, and the value of emotions contributing to attitude is low, an intervention targeting the user's attitude should have a higher priority.

Regarding the second finding, it seems intuitive that a higher level of cues negatively influences physical activity, because people with physical discomforts often find it difficult to exercise or are afraid that exercise will worsen their symptoms. The strong negative correlation between threat and physical activity could be explained by the fact that the questionnaire item assessed with this construct turned out to have low face validity. It assessed the threat of the current physical activity level and not the threat of the consequences of having a chronic disease as the model implies.

Finally, the fact that our results were in line with expected trends but did not show a statistically significant correlation between the first- and second-level determinants could be due to a lack of statistical power, because the relations between these determinants are intuitive and widely reported in psychological and sport literature.

These preliminary results provide empirical support for the main structure of the Combi behavior change model. Note that this study was performed with healthy subjects. Future experiments will be conducted with chronically ill patients—the results of which might show more significant relations between the determinants.

Analysis of eMate Reasoning

A second study examined eMate's reasoning mechanism. This study included 14 chronically ill patients: six with cardiovascular disease and eight with diabetes mellitus type 2. Their ages ranged from 28 to 72 years (with a mean of 50 years), with 11 men and three women. The participants' body mass index ranged from 19 to 37, and nine participants (64 percent) were overweight. Of the overweight participants, two (14 percent) were obese. One participant was underweight.

All participants filled out an updated 76-item questionnaire for physical exercise and food intake. The questionnaire was adjusted according to the participants' feedback and the response data obtained in the study (described earlier).

First, we analyzed the data to identify the subjects' behavioral patterns. The main findings were as follows:

- commitment was most often the underlying bottleneck for behavior change (64 percent);
- of the subjects lacking commitment, 61 percent had the most trouble with coping strategies;
- regarding regular physical exercise, the highest percentage of the subjects regarded themselves in the contemplation stage (36 percent);
- regarding healthy food intake, most percentage of the subjects regarded themselves in the maintenance stage (45 percent); and
- only four out of 14 subjects had different aggregate determinants that are the underlying bottleneck for exercise and food intake.

We compared the data from the questionnaire with the intervention hypotheses that eMate suggested. When eMate identifies a construct as a bottleneck, that construct is viewed as a major obstacle to moving the user to the next stage of change, so appropriate interventions are needed. As discussed earlier, the paths examined for finding such bottlenecks are those connected to the succeeding stage of change. The main trends we found here were as follows:

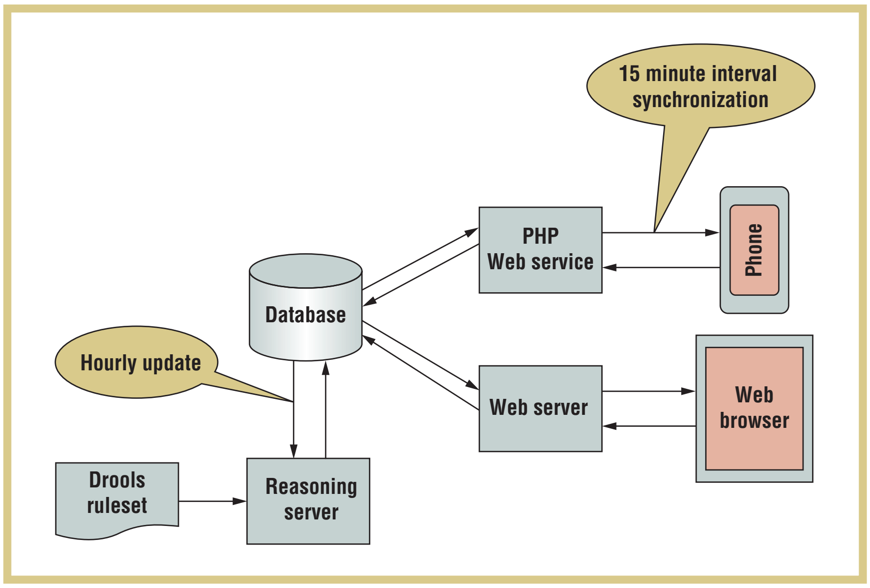

Figure 5. The architecture of the eMate system components.

- in 68 percent of the cases, eMate identified the determinant with the lowest value (as obtained from the patient surveys) in the connected path as a bottleneck;
- in 43 percent of the cases, the hypothesized bottleneck was the lowest determinant in the model, and
- although cues and coping were often the lowest determinants in the model (43 and 57 percent, respectively), only coping was often identified as a bottleneck—in 56 percent of the cases (versus 0 percent for cues).

These results show that eMate's hypotheses of the bottleneck often coincide with the lowest determinants in a path. In cases where it doesn't coincide, eMate arguably chooses a better candidate for intervention, because the search algorithm prunes out less relevant constructs and targets those with a high probability of helping the user move to the next stage of change. For example, if a person's attitude has no problematic value, trying to improve constructs that influence attitude, such as emotion, probably won't change the user's state.

Although these results are interesting, we're aware that they show only trends, because the number of participants is too low to extract any significant findings. Further experiments, as well as an elaborate user design analysis, are needed to review eMate's functioning and effects.

eMate has a strong potential for understanding users' behavior and inducing effective behavior change. It can help users adopt a healthy lifestyle to prevent chronic illness or reduce the number of serious complications associated with such illnesses.

Preliminary results are encouraging regarding the embedded cognitive model of the user and the model's ability to help the system perform intelligent reasoning and intervene as needed. eMate can be adjusted to coach other types of behavior—such as smoking cessation or sustainable behavior—because the general mechanisms for these behavior changes are similar to the ones currently implemented. The rules and tailored messages can also be adapted

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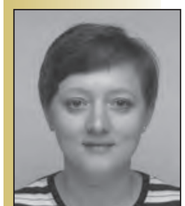

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to include different conditions and requirements. eMate is thus not only a helpful coach but also a resourceful tool for researchers who want to test their theories of behavior change and persuasive interventions.

We're currently performing a full system validation, but a related discussion is beyond this article's scope. We're working to improve the eMate system and will soon conduct an evaluation study with all participants in the pilot study. After analyzing the questionnaire results, we'll fine-tune the system and its underlying procedures. We plan to test and validate the model with larger groups of chronically ill patients.

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